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A web-based virtual lighting simulator

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Abstract

This paper is about a web-based “virtual lighting simulator,” which is intended to allow architects and lighting designers to quickly assess the effect of key parameters on the daylighting and lighting performance in various space types. The virtual lighting simulator consists of a web-based interface that allows navigation through a large database of images and data, which were generated through parametric lighting simulations. At its current form, the virtual lighting simulator has two main modules, one for daylighting and one for electric lighting.

The daylighting module includes images and data for a small office space, varying most key daylighting parameters, such as window size and orientation, glazing type, surface reflectance, sky conditions, time of the year, etc. The electric lighting module includes images and data for five space types (classroom, small office, large open office, warehouse and small retail), varying key lighting parameters, such as the electric lighting system, surface reflectance, dimming/switching, etc.

The computed images include perspectives and plans and are displayed in various formats to support qualitative as well as quantitative assessment. The quantitative information is in the form of iso-contour lines superimposed on the images, as well as false color images and statistical information on work plane illuminance. The qualitative information includes images that are adjusted to account for the sensitivity and adaptation of the human eye. The paper also includes a section on the major technical issues and their resolution.

Introduction

Architects and lighting designers need means to evaluate the effects of design decisions on the luminous performance of their designs. In the past, designers used mostly scale models for qualitative assessment and hand computations for quantitative assessment. As computing power is becoming increasingly affordable, several computer-based daylighting and lighting simulation tools are now available (Ward and Shakespeare 1998; Baty 1996; Hitchcock 1995; Sillion and Peuch 1994). These tools take as input a description of the geometry of the architectural space and the photometric characteristics of all surfaces and light sources, and produce as output either illuminance (light arriving at surface) or luminance (light leaving from a surface) distributions. Some of these tools also produce photometrically accurate renderings, which greatly assist in qualitative assessment of luminous environments. However, the production of renderings usually requires significant computation time, even on fast computers. Depending on the number of surfaces and light sources, and the size and quality of the rendered image, computation time requirements can range from a few minutes for small images of simple spaces, to many hours, days and even weeks for high quality large images of spaces with many surfaces and many light sources.

Computation time requirements as well as time requirements for the preparation of simulation input are the main barriers in the use of lighting simulation and rendering tools. As a result, they are mostly used for the generation of presentation images after the design is mostly complete. During the early, schematic phases of design, lighting and daylighting designers have no means to quickly and easily assess the effect of key parameters on luminous performance. Such key parameters may either refer to the design itself, e.g., window size and orientation, glazing type, lighting fixtures and placement, reflectance of surfaces, etc., or the context of the design project, e.g., location, day of the year, time of the day, etc. Using scale models or simulation tools requires significant time, especially when more than one parameters need to be examined through a range of possible values.

This paper is about a web-based tool that aims at allowing lighting and daylighting designers to quickly and easily assess the effect of key parameters on qualitative and quantitative aspects of daylighting and lighting performance. The tool is based on a large database of images and data, which were generated through a very large numbers of parametric lighting simulations in prototypical architectural spaces. The result is the equivalent of a web-based virtual simulator, which allows users to change the values of critical design and context parameters and displays the corresponding images and data for qualitative and quantitative assessment of the luminous performance.

The paper includes a detailed description of the virtual lighting simulator, which has two main modules: a daylighting and an electric lighting module. The database specifications for both modules are described in detail, along with the web-based user interface. The paper also includes a section on the major technical issues and their resolution.

The Virtual Lighting Simulator

The current version of the virtual lighting simulator has two modules: one for daylighting and one for electric lighting. The daylighting module includes a large number of images and data for a simple, small office space, which were generated through parametric simulations, varying the values of key daylighting parameters. The electric lighting module includes images and data for five space types, which were generated through parametric simulations focusing on electric lighting systems, reflectance of interior surfaces and dimming/switching of light sources. All simulations were performed using Radiance (Ward and Shakespeare, 1998), one of the most accurate lighting simulation software available today, especially for daylighting simulations (Ubbelohde and Humann 1998; Khodulev and Kopylov 1996).

Simulation Models: Input and Output

There are many key daylighting design parameters, such as window size and orientation, glazing type, reflectance of interior surfaces, etc, as well as many key contextual parameters, such as external obstructions, sky conditions, time of the year, etc. The scope of the initial work for the project was limited to parametric variations of a few selected parameters. The complete set of parameters and values considered in the parametric simulations for the daylighting module is presented in **Table 1**.

Table 1: The Key Parameters and Values Used For the Daylighting Module.

Parameters	Values
Window-To-Wall Ratio (%)	15, 30, 45, 60
Glazing Type	Clear, Tinted, Reflective, Low-e, Selective Low-e
Shading	None, Overhang, Overhang with vertical fins
Window Orientation	North, East, South, West
Day of Year	December 21, March 21, June 21
Time of Day	9:00 AM, 12:00 Noon, 3:00 PM
Sky Condition	CIE Overcast, CIE Clear

The electric lighting module focused on the consideration of contemporary lighting designs that exceed Title 24 requirements, for five commercial space types:

- Classroom
- Small office
- Large, open office
- Big box warehouse
- Small retail store

The spaces for the electric lighting module were modeled with complete furniture and detailed modeling of the electric lighting systems. The geometric complexity and number and type of light sources significantly increased simulation times in many cases to several days per simulation on the available computing equipment. Considering the available resources for the project, only selected combinations of key lighting parameters were considered, which varied by space type and lighting system.

The computed parameters include various Radiance output in the form of images as well as statistical data of work plane illuminance (minimum, average and maximum) and electric lighting power densities (installed and used). At least one perspective image and a plan image were generated for each simulation scenario, i.e., a unique combination of values for the key design and context parameters. Each image was produced in four different display types (**Figure 1**):

- Camera exposure, using the average luminance in the scene.
- Human exposure, considering the sensitivity and adaptation of the human eye.
- Camera exposure with superimposed contour lines of luminance or illuminance
- Camera exposure in false color, indicating magnitude of luminance or illuminance.

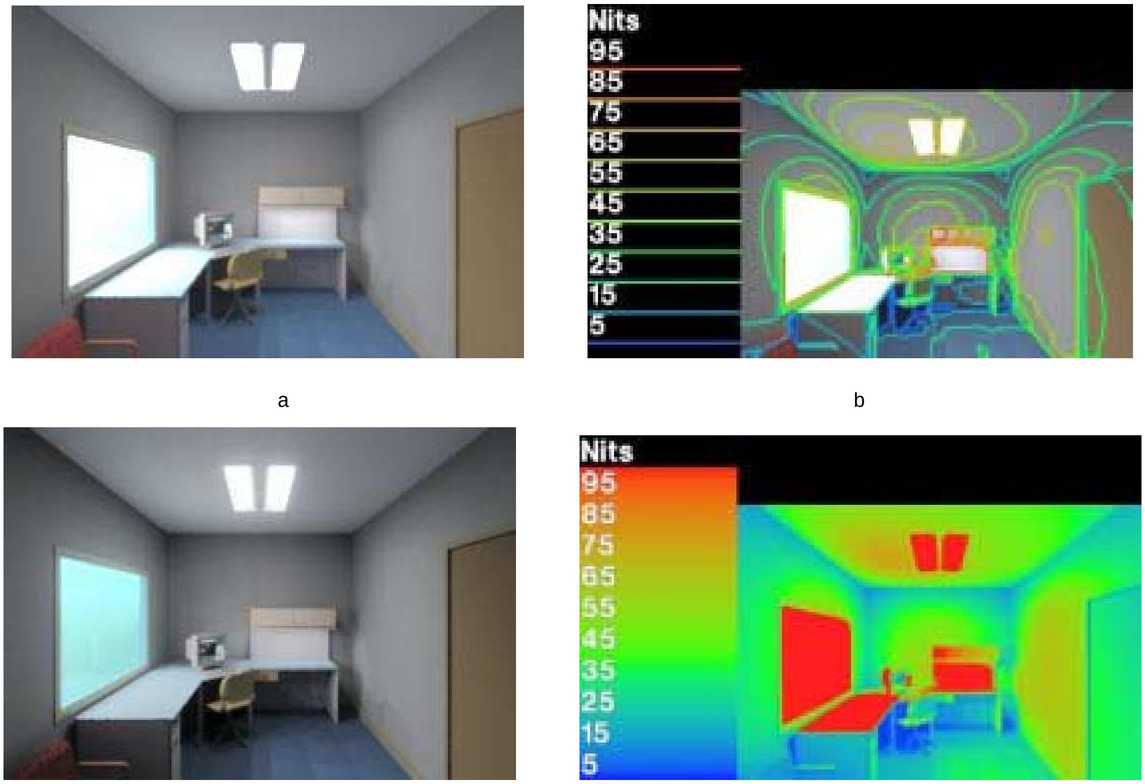

Figure 1. Each image was generated in four display types: “camera” display, based on average luminance (a), “camera” display with superimposed iso-contour lines of luminance or illuminance (b) “human” display, based on the sensitivity and adaptation of the human eye (c), and false color display, showing magnitude of luminance or illuminance (d).

The User Interface

The web-based user interface design was driven by several objectives. It should make, the tool should be easy and intuitive to use; allow comparison of alternatives for perception of value; allow simultaneous quantitative and qualitative assessment; be uniform for both modules and all space types. Finally it should fit into the low end of screen resolutions. All of the above were considered early on for the determination of the image dimensions, prior to starting the Radiance simulations.

The design of the user interface is targeted to a minimum display of 800x600 pixels and consists of three main frames: a header frame and two identical in design frames that allow side-by-side comparison of different scenaria or of the same scenario in different display modes. Two copy buttons at the bottom of the screen allows instant copying of one frame to the other to support quick setting of a base for side-by-side comparison (**Figures 2, 3, 4 and 5**).

Technical Issues and Resolutions

Several technical issues were addressed during the development of this virtual lighting simulator or Radiance Image Database, as we currently refer to it. One of the most important issues was the estimation of the time requirements for the generation of images of high enough quality to be effective for qualitative assessment.

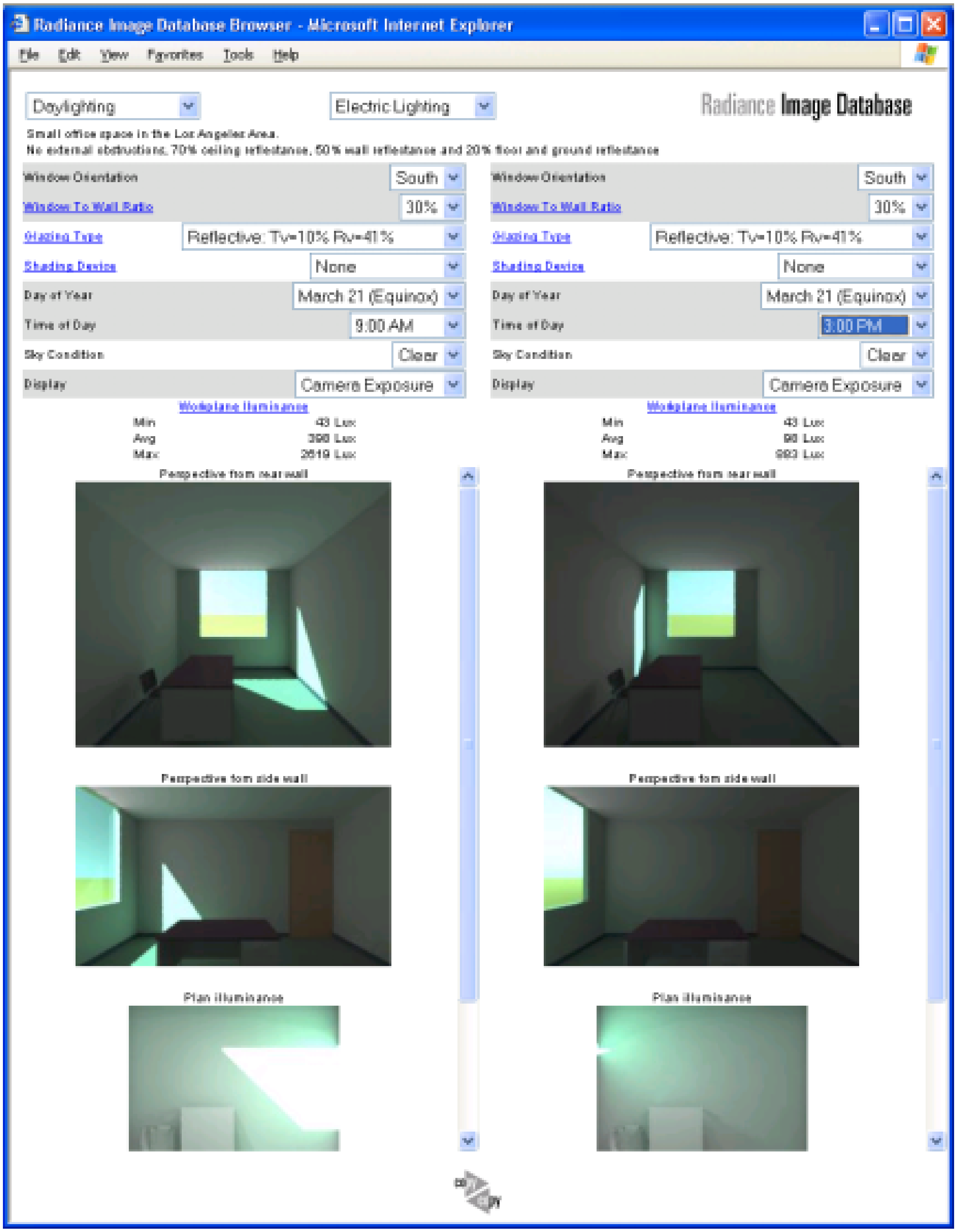

Figure 2. Screen shot of the Daylighting Module, showing camera displays of the small office space facing South, on March 21, at 9:00 AM (left) and 3:00 PM (right).

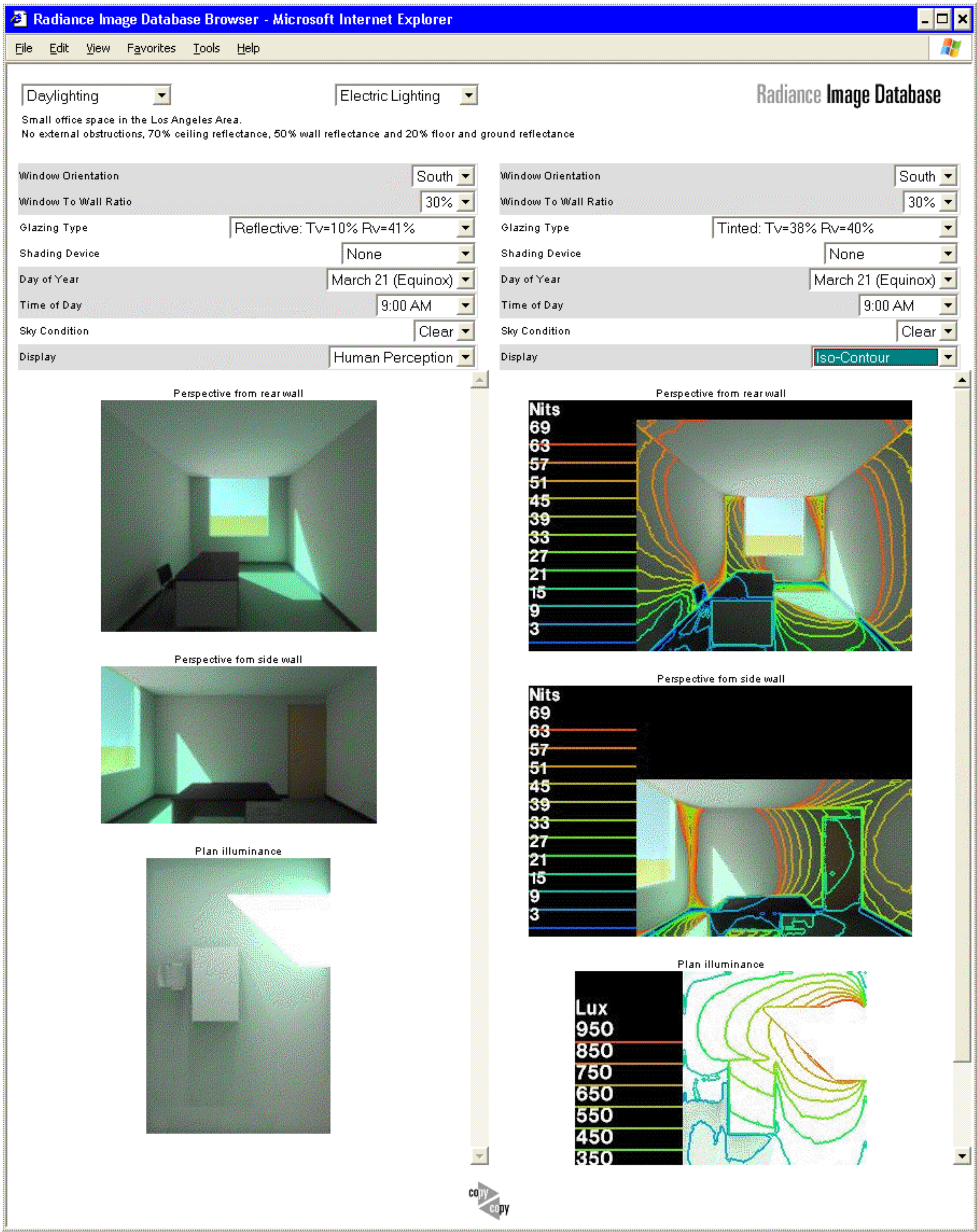

Figure 3. Screen shot of the Daylighting Module, showing the small office space in human sensitivity (left) and iso-contour (right) displays.

Figure 4. Screen shot of the Electric Lighting module, showing camera displays of the classroom space with troffer (left) and direct/indirect pendant (right) luminaires.

The time requirements for the daylighting module were relatively easy to estimate, because of the few interior surfaces and the single daylight source. We used the user-interface considerations to determine the end size of the images, so that they fit in a side-by-side display. We performed several simulations varying key simulation parameters, such as image resolution, number of light bounces, etc. until we found a combination that was offering good enough quality at the size we wanted. To get images of high enough quality, we produced initial images of three times higher resolution and then reduced them and converted them to a format appropriate for viewing over the Internet.

The times required for the electric lighting spaces was very hard to estimate, because it varied significantly with the number of surfaces in each space and the number and type of light sources. The simulation times varied from a couple of hours for the simplest scenaria to several days for the most complicated ones, like the big box warehouse and the small retail store. We had to

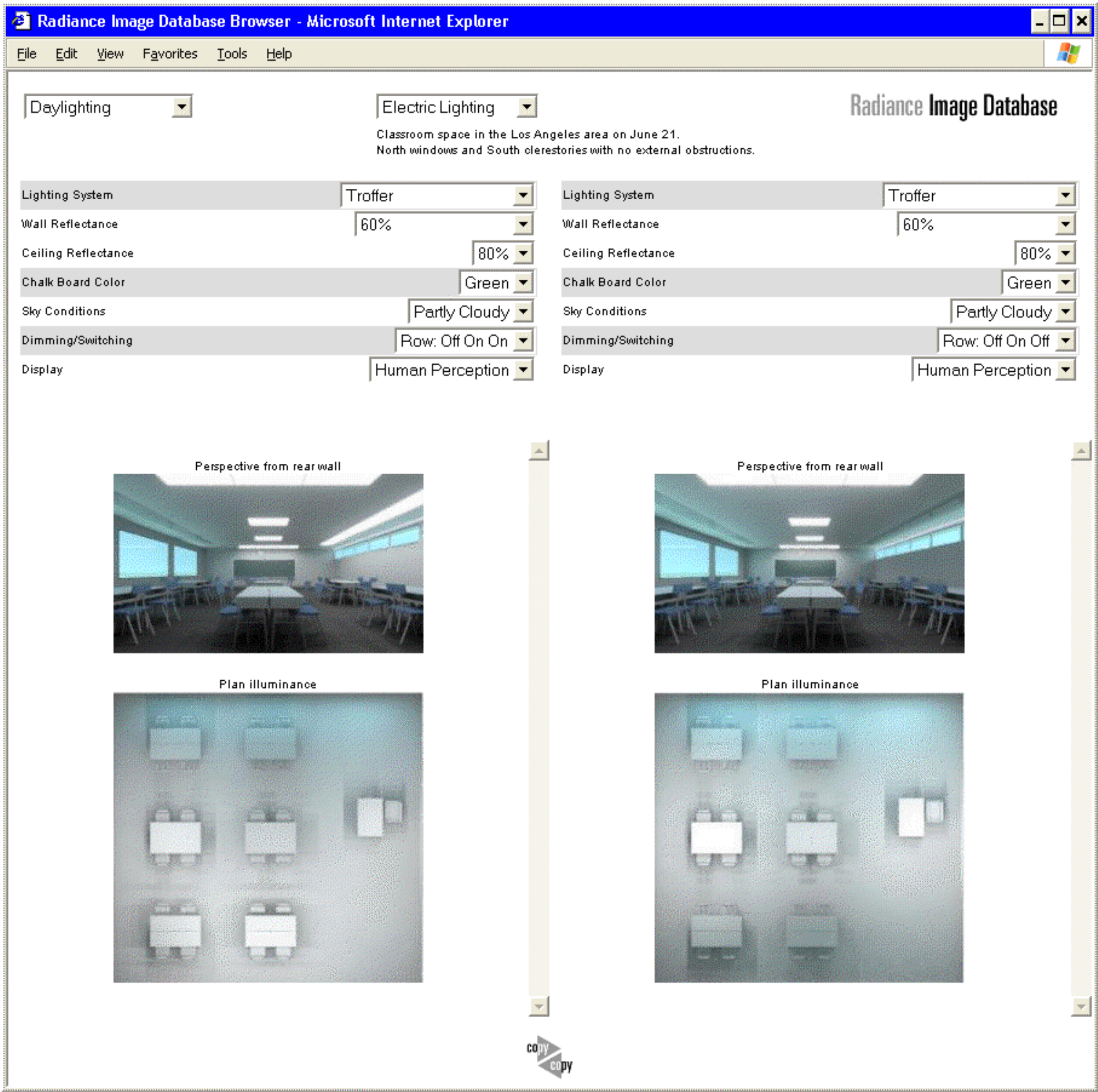

Figure 5. Screen shot of the Electric Lighting Module, showing human sensitivity displays of the classroom space with one row (left) and two rows (right) of lights switched off.

repeat the same process as for the daylighting module, while the test simulations took much longer to perform.

Another major issue was the management of a very large number of computationally intensive simulations, each producing more than 10 images on the average, raising significant computational and data storage and manipulation issues. Even with limited parametric variations, the daylighting module required more than 4,000 simulations and manipulation of more than 50,000 images. The computational issues were successfully addressed using a cluster of eight computers dedicated to this project.

Although Radiance computes the whole range of luminance and illuminance values, computer monitors are limited with respect to the levels of brightness that they can display, raising image exposure issues. These were resolved by using exposure settings based on the average luminance of each image, which represents what a photographic camera would capture. We then generated a separate set of images that were adjusted for the sensitivity and adaptation of the human eye. These images approximate what the human eye would see, thus offering better support for qualitative assessment of lighting conditions.The computation of statistical information on minimum, maximum and average values for work plane illuminance was based on a dense grid calculation, which produced many low values at the grid points that work plane was cutting through furniture. This produced confusing images of work plane illuminance and introduced errors in the statistical computations. To resolve the issue, we developed routines to exclude the low values from the images and the computations of statistical information.

To reduce total simulation time requirements for the electric lighting module, we only simulated specific combinations of values that made sense for the particular space and electric lighting system. For example, we considered electric lighting dimming/switching only for the daytime simulations and varied the ceiling reflectance only for indirect lighting systems. This selective approach resulted in significant user interface complexity because it required dynamic menus, based on the values or combinations of values of other parameters.

Conclusions and Future Directions

The virtual lighting simulator allows for quick and easy assessment of the effects of key daylighting and lighting parameters on the luminous performance of various space types. It makes it very easy to compare alternative daylighting and electric lighting designs. However, in its current form it is limited to the specific combinations of input values that were considered for the initial set of parametric simulations.

The tool can be expanded to include more locations, representing a wide range of latitudes, to be useful to a wider audience. It can also be expanded to include more space types, glazing types and electric lighting designs, as well as include consideration of skylights and more dimming and switching combinations for electric lighting. Finally it can be expanded with respect to usability features, such as search functions for scenaria that meet more specific criteria with respect to input as well as output parameters.

We plan to base our decisions on future expansions on user feedback. We are also looking into the possibility of supporting automatic expansion of the tool through dynamic Radiance simulations, using distributed computing techniques to speed up the process of generating images for new scenaria. In this mode, users would be able to specify new combinations of input values and generate new sets of images that are automatically added to the database.

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